

**APPLICATION**

**FOR**

**UNITED STATES LETTERS PATENT**

**TITLE:            SEGMENTED WAVEGUIDE COUPLER**

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## SEGMENTED WAVEGUIDE COUPLER

### Background

This invention relates generally to couplers for coupling optical signals.

Couplers couple a signal transmitted through a first  
5 waveguide into a second waveguide. Couplers may use fibers or planar waveguides.

In a planar waveguide, the optical paths are formed on a substrate using semiconductor processing techniques. A light path may travel through a so-called optical core  
10 formed over the substrate. The core may be covered with an appropriate cladding. The optical signal is transmitted through the core and, in some cases, may extend into the cladding. In fact, typically only about 70 percent of the light actually travels inside the core of a waveguide. The  
15 remaining 30 percent propagates in the cladding region outside the core.

With existing couplers, control over the degree of coupling is achieved by controlling the degree of spacing between the waveguides to be coupled. It would also be  
20 desirable to control one or more of the coupling ratio, wavelength dependence, and polarization dependence for applications ranging from simple optical filters to complex waveguides filters and polarization controlling elements.

### Brief Description of the Drawings

Figure 1 is a top plan view a planar light wave circuit in accordance with one embodiment of the present invention;

5        Figure 2 is an enlarged, partial top plan view of a portion of one of the waveguides shown in Figure 1 in accordance with one embodiment of the present invention;

Figure 2A is a hypothetical Gaussian mode-field depiction of a signal at the point A in Figure 2;

10       Figure 2B is a hypothetical Gaussian mode-field depiction of a signal in the gap B in Figure 2;

Figure 2C is a hypothetical Gaussian mode-field depiction of a signal at the point C in Figure 2; and

15       Figure 2D is a hypothetical Gaussian mode-field depiction of a signal at the point D in Figure 2.

### Detailed Description

Referring to Figure 1, a planar light wave circuit 10 may be formed on a semiconductor substrate using semiconductor integrated circuit fabrication techniques. A pair of waveguide cores 14 and 16 may be defined on a planar light wave circuit 10. Waveguide cores 14 and 16 may be brought into relatively close proximity at the segmented regions 12a and 12b. Each core 14 and 16 may be defined by conventional semiconductor processing techniques such as deposition and etching. The formation of the segmented regions 12 and the gaps therebetween may be

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readily formed by patterning and etching techniques in one embodiment of the present invention.

In one embodiment of the present invention, the segmented regions 12a and 12b may be brought to close  
5 proximity to one another, for example in the range of 1 to 10 microns. The length of the segmented regions 12a and 12b, in one embodiment, may be on the order of a few hundred microns to allow light to couple from one waveguide 14 or 16 to the other waveguide 14 or 16.

10 The pattern of gaps in the segmented regions 12a and 12b may be engineered to control the mode size and mode overlap integral in the coupling region and ultimately to control the coupling energy. Thus, in some embodiments of the present invention, one or more of the coupling ratio,  
15 wavelength dependence, and polarization dependence may be controlled with a desirable degree of precision by engineering the arrangement of the gaps.

In some embodiments, the lengths of the gaps in the regions 12a and 12b may be different along the lengths of  
20 the regions 12a and 12b. In some embodiments, the spacing and size of the gaps may be regular and repetitive. In other embodiments, the arrangement of the gaps in the region 12a may be different than the arrangement of the gaps in the region 12b.

25 Referring to Figure 2, a waveguide region 12, which may correspond to the region 12a or 12b in Figure 1, may have a gap indicated at B. The size of the gap B may be

controlled to achieve the desired coupling characteristics.  
The width of the waveguide is indicated as E in this  
embodiment. While a two-dimensional depiction is indicated  
by Figure 2, those skilled in the art will appreciate that  
5 characteristics in the dimension into the page may also be  
relevant. However, for simplicity, a two-dimensional  
explanation follows for one embodiment of the present  
invention.

A light signal at the point A in the waveguide region  
10 12 may have the Gaussian mode-field signal M1 indicated at  
Figure 2A. The width of the signal may correspond to the  
width E of the waveguide as indicated in Figures 2 and 2A.

As the signal M1 propagates along from left to right,  
the light signal passes the point A, and eventually enters  
15 the gap B. As it extends into the gap or free space  
region, the light signal continues to expand indefinitely  
the Gaussian mode-field characteristics shown in Figure 2B.  
In this case, the width F of the signal corresponds to a  
maximum width resulting from the characteristics of the  
20 signal and the size of the gap B.

Thereafter, as the signal continues to move from left  
to right, it encounters the reduced area of the end of the  
rightmost portion of the region 12 having a width E. The  
signal progressively reduces its Gaussian mode-field width  
25 to point C as shown in Figure 2C, eventually reaching the  
point D and exhibiting the mode-field characteristics shown  
in Figure 2D.

In Figure 2D, the Gaussian mode-field is a Gaussian signal having a width  $E$ . At the point C, illustrated in Figure 2C, the signal may have a mode-field having a width somewhere between that shown in Figure 2B and that shown in  
5 Figure 2D, but in any case less than the width shown in Figure 2B and less than the maximum width achieved in the gap B.

Thus, as the light enters the waveguide region 12, it contracts to fill the certain space that depends on the  
10 geometry, the index of refraction and the wavelength. That signal maintains that shape on propagation through the waveguide. When the light leaves the waveguide, it starts expanding slowly and steadily. If the light hits another waveguide segment it starts contracting again until it  
15 reaches its natural beam width. Thus, for a series of segments, the light expands and contracts periodically, but ends up having an average width called the average mode-field diameter determined by the characteristics of the gaps between segments.

20 By adjusting the segmentation pattern of the waveguide regions 12a and 12b, the mode profile may be tailored for the coupled light propagated through the waveguides. The light may expand or contract its mode-field diameter as a function of position. This expanding and contracting of  
25 the mode-field diameter allows for the control of the coupling characteristics of the two waveguides 14 and 16

placed in close proximity to one another. The mode profile may be controlled by controlling the segmentation pattern.

The segmentation pattern is much less critically dependent on lithographic capabilities than, for example,  
5 the variable core width couplers. The mode confinement technique works in three dimensions and, therefore, suffers less from induced polarization dependencies than would arise with a two-dimensional approach, at least in some embodiments.

10 The coupling characteristics between the segments 12a and 12b are governed by the overlap integral of the modes in the two separate waveguides 14 and 16 that have been brought into close proximity. By controlling the mode-field size through segmentation of the waveguides, it is  
15 thereby possible to control the coupling ratio. The mode-field diameter can be controlled separately for the waveguides 14 and 16. The mode-field can also be varied along the length of a waveguide.

While the present invention has been described with  
20 respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

25 What is claimed is: